PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter II of the Patent Cooperation Treaty)

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference TS 6401 PCT	**FOR FURTHER ACTION**	See Form PCT/IPEA/416
International application No. PCT/EP2004/053675	International filing date *(day/month/year)* 22.12.2004	Priority date *(day/month/year)* 24.12.2003
International Patent Classification (IPC) or national classification and IPC E21B47/10		
Applicant SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.		

1. This report is the international preliminary examination report, established by this International Preliminary Examining Authority under Article 35 and transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 6 sheets, including this cover sheet.
3. This report is also accompanied by ANNEXES, comprising:
   a. ☒ *sent to the applicant and to the International Bureau)* a total of 9 sheets, as follows:
      - ☒ sheets of the description, claims and/or drawings which have been amended and are the basis of this report and/or sheets containing rectifications authorized by this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions).
      - ☐ sheets which supersede earlier sheets, but which this Authority considers contain an amendment that goes beyond the disclosure in the international application as filed, as indicated in item 4 of Box No. I and the Supplemental Box.

   b. ☐ *(sent to the International Bureau only)* a total of (indicate type and number of electronic carrier(s)) , containing a sequence listing and/or tables related thereto, in computer readable form only, as indicated in the Supplemental Box Relating to Sequence Listing (see Section 802 of the Administrative Instructions).

4. This report contains indications relating to the following items:

☒ Box No. I	Basis of the opinion
☐ Box No. II	Priority
☐ Box No. III	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
☐ Box No. IV	Lack of unity of invention
☒ Box No. V	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
☐ Box No. VI	Certain documents cited
☐ Box No. VII	Certain defects in the international application
☐ Box No. VIII	Certain observations on the international application

Date of submission of the demand 13.10.2005	Date of completion of this report 09.01.2006
Name and mailing address of the international preliminary examining authority: European Patent Office - P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk - Pays Bas Tel. +31 70 340 - 2040 Tx: 31 651 epo nl Fax: +31 70 340 - 3016	Authorized Officer van Berlo, A Telephone No. +31 70 340-3535

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

International application No.
PCT/EP2004/053675

Box No. I Basis of the report

1. With regard to the **language**, this report is based on the international application in the language in which it was filed, unless otherwise indicated under this item.

   ☐ This report is based on translations from the original language into the following language , which is the language of a translation furnished for the purposes of:

   ☐ international search (under Rules 12.3 and 23.1(b))
   ☐ publication of the international application (under Rule 12.4)
   ☐ international preliminary examination (under Rules 55.2 and/or 55.3)

2. With regard to the **elements*** of the international application, this report is based on *(replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report)*:

Description, Pages

1, 2, 6-15, 18, 19	as originally filed
3-5, 16, 17	received on 24.10.2005 with letter of 24.10.2005

Claims, Numbers

1-11	received on 24.10.2005 with letter of 24.10.2005

Drawings, Sheets

1/3-3/3	as originally filed

☐ a sequence listing and/or any related table(s) - see Supplemental Box Relating to Sequence Listing

3. ☐ The amendments have resulted in the cancellation of:

   ☐ the description, pages
   ☐ the claims, Nos.
   ☐ the drawings, sheets/figs
   ☐ the sequence listing *(specify)*:
   ☐ any table(s) related to sequence listing *(specify)*:

4. ☐ This report has been established as if (some of) the amendments annexed to this report and listed below had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).

   ☐ the description, pages
   ☐ the claims, Nos.
   ☐ the drawings, sheets/figs
   ☐ the sequence listing *(specify)*:
   ☐ any table(s) related to sequence listing *(specify)*:

* *If item 4 applies, some or all of these sheets may be marked "superseded."*

Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	4-11
	No:	Claims	1-3
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-11
Industrial applicability (IA)	Yes:	Claims	1-11
	No:	Claims	

2. Citations and explanations (Rule 70.7):

see separate sheet

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. The present application does not meet the criteria of Article 33(1) PCT, because the subject-matter of amended claim 1 (combination of original claims 1, 4 and 5) is not new in the sense of Article 33(2) PCT.

2.1 The document US2003140711 discloses, in particular in paragraph 73 to 97 and figures 9 to 18:

A method of determining a fluid inflow profile along the length of a permeable inflow region of an underground wellbore, the method comprising the steps of:
- transferring heat into or from the permeable inflow region of the wellbore during a well shut in period such that at least a substantial part of the inflow region has a temperature which is different from the temperature of the surrounding formation;
- starting production of hydrocarbon fluids via said permeable inflow region;
- measuring substantially simultaneously the temperature of the fluids at various points along at least part of the length of the inflow region;
- determining at selected intervals of time after production start up a temperature profile along at least part of the length of the inflow region or the basis of the thus measured temperatures; and
- determining a fluid inflow profile along the length of said inflow region on the basis of a comparison of the determined temperature profiles at selected intervals after production start up,
- wherein at least a substantial part of the permeable inflow region is heated during the well shut-in period and wherein during an initial period of time after starting production of hydrocarbons via said permeable inflow region heating of the permeable inflow region is continued and wherein during a subsequent period of time following said initial period heating of the permeable inflow region is interrupted, and the temperature is measured both during said initial and subsequent periods of time, and
- wherein differences between the temperature variation over time measured during said initial and subsequent period are used to determine a heat capacity of the inflowing fluid.

The subject-matter of claim 1 is therefore not new, see also 2.2 to 2.4.

2.2 Particularly the last sentence of paragraph 86 of the document US2003140711 discloses the last part of amended claim 1 in the sense that if no minimum measurable temperature drop can be established, the heat capacity of the flowing oil is so big that the temperature drop achieved during the cooling is below the temperature measurement threshold. In other words, no measurable temperature drop means a too high heat capacity of the inflowing oil (and therefore the need for a longer cooling period).

2.3 It is noted that claim 1 does not describe a method which measures 'what fluids and where the different fluids flow into the well'. The measurements described in claim 1 are 'used to determine *a heat capacity* of the inflowing fluid', which can depend as much on the mass(-flowrate) of the inflowing fluid as on the *specific heat capacity* of the inflowing fluid. Claim 1 does for example not refer to *specific heat capacities* of different fluids.

2.4 The use of heating rather than cooling is considered trivial from US2003140711 in the light of paragraph 102.

3. Dependent claims 2-3 and 9 do not appear to contain any additional features which, in combination with the features of any claim to which they refer, meet the requirements of the PCT with respect to novelty, the reasons being as follows:

- Claim 2 and 3 describe the use of thermal indicators which are trivial to the man skilled in the art. The subject-matter of claim 2 and 3 is therefore not novel.

- In claim 9 the definition of 'an optimal level' is not clear and as such the claim does not meet the requirements of Article 6 PCT. Furthermore, the above-mentioned lack of clarity notwithstanding, the subject-matter of said claim is not new in the sense of Article 33(2) PCT, and therefore the criteria of Article 33(1) PCT are not met.

- Dependent claims 4-8,10 and 11 do not appear to contain any additional features which, in combination with the features of any claim to which they refer, meet the requirements of the PCT with respect to inventive step, the reasons being as follows:

- The use of temperature variations over time in combination with heating as an

indicator for differences in heat capacity and fluids is well known, see for example DE10149092. The skilled person would therefore regard it as normal to use this feature in combination with US2003140711 to indicate differences in the inflowing fluid.
Claims 4 and 5 are therefore not inventive.

- The combination of an electrical heater with a fiber optical temperature sensor is known from cited document WO0011317. Claim 6 is therefore not inventive.

- In addition to the foregoing the feature of either strapping the optical fiber on the outer face of the electrical heater cable or embedding it in the mineral insulation layer, which in itself is known from US-A-4.570.715, is merely one of several straightforward possibilities from which the skilled person would select, without the exercise of inventive skill. Claim 7 and 8 are therefore not inventive.

- For system claims 10 and 11 the same reasoning as for claim 7 and 8 is also applicable and these claims are therefore also not inventive.

at least a substantial part of the length of a fluid inflow region of a well, which can be configured to provide information about the heat capacity and/or composition of the fluid flowing from the formation into the well at various points along the length of the inflow region.

SUMMARY OF THE INVENTION

The method according to the invention for determining a fluid inflow profile along the length of a permeable inflow region of an underground wellbore comprises the steps of:

- transferring heat into or from the permeable inflow region of the wellbore during a well shut in period such that at least a substantial part of the inflow region has a temperature which is different from the temperature of the surrounding formation;
- starting production of hydrocarbon fluids via said permeable inflow region;
- measuring substantially simultaneously the temperature of the fluids at various points along at least part of the length of the inflow region;
- determining at selected intervals of time after production start up a temperature profile along at least part of the length of the inflow region on the basis of the thus measured temperatures ; and
- determining a fluid inflow profile along the length of said inflow region on the basis of a comparison of the determined temperature profiles at selected intervals after production start up , wherein at least a substantial part of the permeable inflow region is heated during the well shut-in period and wherein during an initial period of time after starting production of hydrocarbons via said permeable inflow region heating of

the permeable inflow region is continued and wherein during a subsequent period of time following said initial period heating of the permeable inflow region is interrupted, and the temperature is measured both during said initial and subsequent periods of time and wherein differences between the temperature variation over time measured during said initial and subsequent period are used to determine a heat capacity of the inflowing fluid.

The level of temperature variation per unit of time, such as the local heat up or cool down rate, may used as an indicator of the level of influx of fluid at various points along the length of said inflow region.

In case during a shut in, when no fluids flow into the well, a well inflow region is heated by an electrical heater cable which has a substantially constant electrical resistance along the length of the heated section this will result in an substantially constant increase in well temperature over time along the heated section. When the well is put back on production the zones with relatively high flow rates will cool down to reservoir temperature faster than zones with no or little fluid flow.

Accordingly, the inflow profile may be determined such that if at a specific location the measured temperature variation over time is higher than at adjacent locations along the length of the permeable inflow region the thus measured peak in the temperature variation per unit of time is used as an indicator that at said specific location the influx of fluids is higher than at said adjacent locations, whereas if at another specific location the measured temperature variation per unit of time is lower than at adjacent locations along the length of the permeable inflow region the thus

measured dip in the temperature variation per unit of time is used as an indicator that at said other specific location the influx of fluids is lower than at said adjacent locations.

It is observed that US patent application US 2003/0140711 discloses a method for measuring the fluid velocity in a well by monitoring the upward migration of a cold spot created during well shut in. The known method does not measure the fluid inflow profile in the well inflow region and does not monitor where and/or what fluids flow into the well by comparing cool down/heat up rates at different points along the length of the well inflow region.

In the method according to the invention a ratio of the temperature variation over time measured during the initial period and during the subsequent period is determined for various points along the length of the inflow region and said ratio is used as an indicator of the heat capacity of the fluid flowing into the well. More particularly, a relatively high ratio between the temperature variation measured during the initial and subsequent periods may be used as an indicator that the inflowing fluid has a relatively low heat capacity and a relatively high gas content.

It is observed that German patent application DE 10149092 discloses a method for monitoring the liquid level in a salt cavern for storage of natural gas wherein the cavern is heated by a heater cable and the liquid level is monitored by measuring the heat up rate of a fibre optical temperature sensor adjacent to the heater

4. Put the well back under producing condition with the heater still on. Obtain a steady-state temperature profile.

5. Turn off the heater and obtain a steady state temperature profile (the same as the temperature profile in step 1. The transient behaviour and the time it takes to get from step 4 to 5 can be used to determine an inflow distribution for the different phases.

Steps 1 and 2 form part of the known procedure for obtaining temperature data with DTS in order to obtain a qualitative "single-phase" (total liquid) inflow distribution.

Steps 3 to 5 are the additional steps required to go from a qualitative to a quantitative multi-phase measurement with the use of a heater.

Simulations of the method according to the invention have been carried out with a thermal reservoir model. In figure 5, simulated results are shown for a well with a horizontal section of 600 meters. The horizontal section has been subdivided into three areas with different reservoir characteristics, i.e. different permeabilities of 10, 250 and 100 mD, respectively. Thus, the reservoir has a decreasing permeability along the well.

The lower horizontal line 30 shows the temperature profile of a well that is shut-in just before the heater is activated. The upper horizontal line 31 shows the temperature profile after 48 hour of heating up the well with 90 W/m (So about 60 kW for the whole horizontal sections). After 48 hours the heater is turned off and the well is put on production. The rest of the temperature profiles 32-36 show the temperature response over time. The time it takes for the well to cool down to the temperature profile prior to shut-in can be correlated to the inflow from the reservoir.

A physical model that demonstrates that the method according to the invention can be used to estimate the velocities and/or composition, such as the watercut, of the fluids flowing into the well is as follows.

If a fluid is not in thermal equilibrium with the porous medium it is flowing through, heat will either be extracted or provided to the medium. The temperature of the moving fluid changes corresponding to the temperature of the porous medium and depending on its heat capacity. The basic equation is

$$\nabla(\nabla T) - \frac{(\rho \cdot c)_f}{\lambda} \cdot \nabla(\vec{v} \cdot T) = 0 \qquad (1)$$

where ∇ is the spatial derivative, T is temperature, ρ is density and c is heat capacity of the fluid, λ is thermal conductivity of the saturated medium, and $\vec{v}$ is the Darcy velocity of the fluid, which can be translated into the actual flow velocity $\vec{V}$ by

$$\vec{V} = \frac{\vec{v}}{\phi} \qquad (2)$$

where ϕ is the porosity.

For one spatial component, e.g. the vertical direction z, the analytic solution to equation (1) is

$$T = T_0 + (T_L - T_0) \cdot \frac{\exp\left\{\frac{z \cdot Pe}{L}\right\} - 1}{\exp\{z \cdot Pe\} - 1} \qquad (3)$$

where T_0 is the temperature at z = 0, T_L is the temperature at z = L, L is the section of interest, and Pe is the Peclét number, defined as the ratio of convective to conductive heat flow

CLAIMS

1. A method of determining a fluid inflow profile along the length of a permeable inflow region of an underground wellbore, the method comprising the steps of:

- transferring heat into or from the permeable inflow region of the wellbore during a well shut in period such that at least a substantial part of the inflow region has a temperature which is different from the temperature of the surrounding formation;
- starting production of hydrocarbon fluids via said permeable inflow region;
- measuring substantially simultaneously the temperature of the fluids at various points along at least part of the length of the inflow region; and
- determining at selected intervals of time after production start up a temperature profile along at least part of the length of the inflow region on the basis of the thus measured temperatures;

characterised in that the method further comprises determining a fluid inflow profile along the length of said inflow region on the basis of a comparison of the determined temperature profiles at selected intervals after production start up, wherein at least a substantial part of the permeable inflow region is heated during the well shut-in period and wherein during an initial period of time after starting production of hydrocarbons via said permeable inflow region heating of the permeable inflow region is continued and wherein during a subsequent period of time following said initial period heating of the permeable inflow region is interrupted,

and the temperature is measured both during said initial and subsequent periods of time and wherein differences between the temperature variation over time measured during said initial and subsequent period are used to determine a heat capacity of the inflowing fluid.

2. The method of claim 1, wherein the level of temperature variation per unit of time is used as an indicator of the level of influx of fluid at various points along the length of said inflow region.

3. The method of claim 2, wherein the inflow profile is determined such that if at a specific location the measured temperature variation over time is higher than at adjacent locations along the length of the permeable inflow region the thus measured peak in the temperature variation per unit of time is used as an indicator that at said specific location the influx of fluids is higher than at said adjacent locations, whereas if at another specific location the measured temperature variation per unit of time is lower than at adjacent locations along the length of the permeable inflow region the thus measured dip in the temperature variation per unit of time is used as an indicator that at said other specific location the influx of fluids is lower than at said adjacent locations.

4. The method of claim 1, wherein a ratio of the temperature variation over time measured during the initial period and during the subsequent period is determined for various points along the length of the inflow region and wherein said ratio is used as an indicator of the heat capacity of the fluid flowing into the well.

5. The method of claim 4, wherein a relatively high ratio between the temperature variation measured during

the initial and subsequent periods is used as an indicator that the inflowing fluid has a relatively low heat capacity and a relatively high gas content.

6. The method of any preceding claim, wherein the permeable inflow region is heated by an electrical heater cable extending along at least a substantial part of the length of the permeable inflow region and wherein the temperature is measured by means of a fiber optical temperature sensor extending along at least a substantial part of the length of the permeable inflow region.

7. The method of claim 6, wherein the fiber optical temperature sensor is strapped to the outer surface of the electrical heater cable.

8. The method of claim 6, wherein the electrical heater cable comprises an electrical conductor which is surrounded by a mineral insulation layer comprising a compacted mineral powder, which layer is enclosed in an annular metal sheath, and the fiber optical sensor is embedded in a channel extending through the mineral insulation layer.

9. A method of producing crude oil from a subterranean formation, wherein the influx of crude oil and/or other fluids into the well is determined and/or adjusted to an optimal level on the basis of the method according to any one of claims 1-8.

10. A heater and distributed temperature sensing system suitable for use in the method according to any one of claims 1 to 9, comprising a one or more mineral insulated heater cables, which each comprise an electrical conductor which is surrounded by a mineral insulation layer comprising an compacted mineral powder, which layer is enclosed in an annular metal sheath, and a fiber optical distributed temperature sensor which extends

along at least a substantial part of the length of one or more mineral insulated heater cables .

11. The heated and distributed temperature sensing system of claim 10, wherein at least one fiber optical distributed temperature sensor extends through a channel extending through the mineral insulation layer of at least one of the mineral insulated heater cables.